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LISA A low Resolution MIR/FIR Imaging Spectrograph for SOFIA

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Abstract. LISA is a proposed low resolution ($R \sim 15\text{--}30$) imaging spectrometer for SOFIA, the American-German Stratospheric Observatory for Infrared Astronomy. Covering the wavelength range from $40\mu\text{m}$ to $220\mu\text{m}$ with three channels, LISA provides diffraction limited spectroscopy for each pixel within a rectangular field of view (FOV). The FOV sizes for the channels are $18 \times 11''$ for 40 to $70\mu\text{m}$, $32 \times 19''$ for 70- $120\mu\text{m}$, and $22 \times 22''$ for 120- $220\mu\text{m}$, each channel upgradable to about twice the linear size.

LISA will be able to address a variety of astrophysical topics, in particular on faint targets. Spatially resolved temperature distribution of dust emission can be studied in the environments of young and evolved stars, star forming regions, as well as in nuclear regions of nearby galaxies. Spectral energy distributions (SEDs) of distant galaxies will be determined in search for cold gas and dust components. LISA's spectral resolution will be high enough to search for broad spectral features (e.g. PAHs, ices). The optical design, the mechanical layout, the estimated sensitivity, and the scientific potential of such an instrument are briefly discussed.

1. Introduction

SOFIA, the Stratospheric Observatory For Infrared Astronomy, will be the biggest and probably the only platform with regular access to the entire MIR and FIR wavelength range between 25 and $250\mu\text{m}$ in both celestial hemispheres for the next two decades. From 2002 on it will open a new era in MIR/FIR astronomy, providing the highest available spatial resolution in combination with excellent sensitivity. SOFIA is a 2.7m telescope onboard a Boeing 747SP flying at an altitude of between 31000 up to 45000 feet during typically 7 hours observing flights. 10 facility, PI and special purpose instruments have already been selected and approved for first light.

Here we present a concept study of LISA, a highly efficient Low resolution Integral field Spectrometer for SPICA, which is considered to become part of the proposed Spectral-Photometric Far-Infrared Camera SPICA (see Wolf et al., this issue) for SOFIA. LISA will be a self-contained subunit of SPICA, complementing it with diffraction limited integral field spectroscopic capabilities at low spectral resolution of about $R \sim 20$.

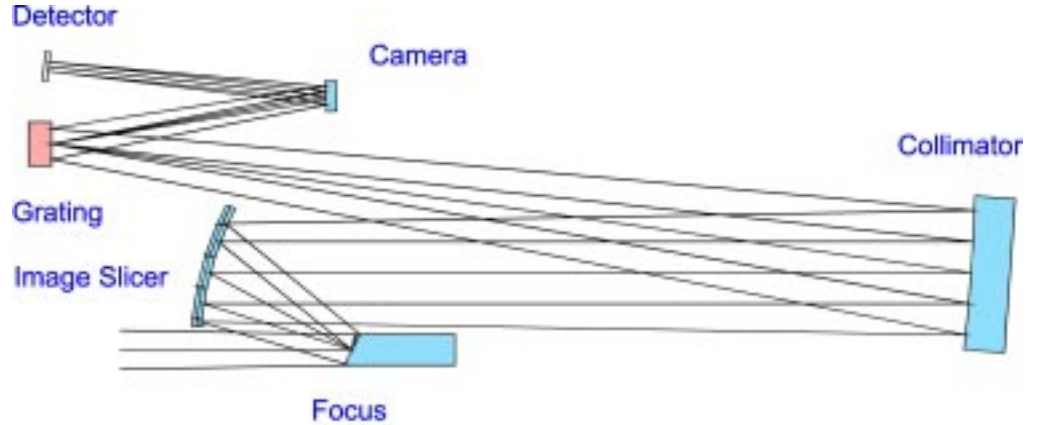


Figure 1. LISA's 70 - 120 μm spectrometer channel.

2. Instrument Concept

The wavelength range covering 2.5 octaves is divided into 3 separate intervals, each of which is fed into a separate grating spectrometer unit. The spectral resolution in each channel varies between 16 and 28 thus covering the whole spectral range with about 36 independent spectral resolution elements. Fully sampled spectra can be obtained by tilting the grating slightly by a fixed amount, such that the spectra are shifted by half a pixel across the array in the dispersion direction. The current design is optimized for 32×32 pixel Ge:Ga detectors with $350 \mu\text{m}$ pixel pitch and 16×16 stressed Ge:Ga with 4mm pitch, but can easily be extended to accommodate larger e.g. 64×64 pixel detectors. The only moving part within LISA will be the grating tilt mechanisms.

An imaging spectrometer was given preference over a set of narrow band filters for several reasons:

- Flat-top high transmission narrow-band filters with $\lambda/\Delta\lambda \sim 6-20$ covering the spectral range $40 \mu\text{m} - 220 \mu\text{m}$ are not available. The 3 broad-band ($\lambda/\Delta\lambda \sim 2$) order sorting filter for LISA will have higher transmission and a better blocking than existing narrow-band filter.
- The data sets obtained with an imaging spectrometer are more consistent and always complete. Since this instrument will obtain a data cube during each individual integration, varying observing conditions will effect all data consistently in the same fashion. Such changes during the flight include variation of seeing, air mass, water vapor & atmospheric transmission, residuals in telescope tracking, pointing, image rotation & structural bending, as well as detector performance & temperature variations. Under unfavorable conditions, these modulations will introduce systematic noise into nonmultiplexed data, thus lowering the effective signal/noise ratio significantly.
- The integration time per target is limited to typically 3 hours per target and the risk of unexpected technical events on an airborne telescope is

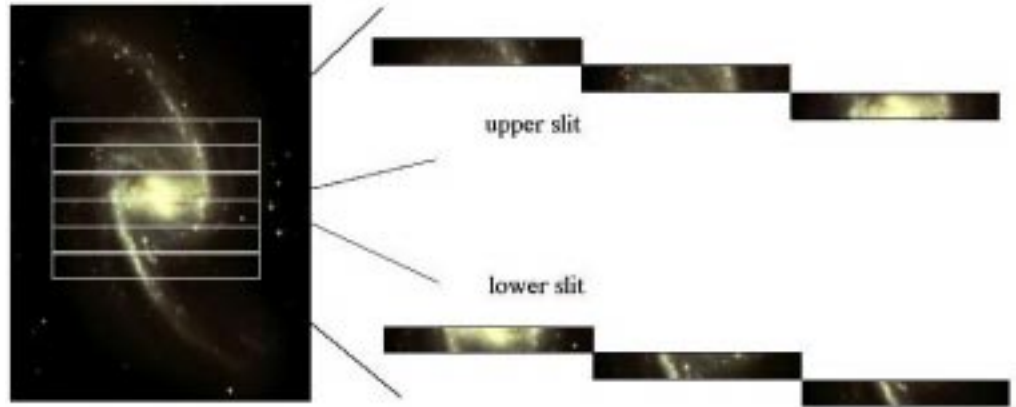


Figure 2. The working principle of the image slicer. A rectangular field in the sky is split into six individual stripes, which are realigned to form two parallel entrance slits at the input of a grating spectrograph.

slightly higher compared to a ground based observatory. Under such conditions most efficient and multiplexing observing techniques are strongly advised. In addition, spectral multiplexing avoids overheads created by the need to frequently changing the setting of the instrument. Under less than optimal observing conditions, consistent spectral information is at least as important as enhanced spatial resolution.

- Most targets under consideration only cover a fraction of the detector area, in particular if even larger arrays become available. Imaging spectroscopy uses the whole array since it distributes spectral as well as spatial information across it and thus maximizes the observing efficiency at any time.
- An imaging spectrometer does not require an excellent pointing of the telescope to put a target on a narrow slit. Its field of view (FOV) is much wider and the pointing effort is more comparable to an instrument using narrow band filters.
- The imaging capabilities of such a spectrometer can be used to acquire the target or to check its position during the integration. A two dimensional image can always be extracted by collapsing the spectral information and rearranging the pixels according to their proper location on the sky.

3. Optical design

The basic design of LISA is that of a long slit spectrometer (Figure 1) with two parallel input slits. The spectrometer is designed such that both entrance slits are dispersed into nonoverlapping spectra on the array. A system of optical flat mirrors, the image slicer, rearranges the two slits into one rectangular FOV on the sky. Figure 2 explains the slicing technique on the slicer for the 70 - 120 μ m wavelength range. Figure 3 shows a close up view of the image slicer

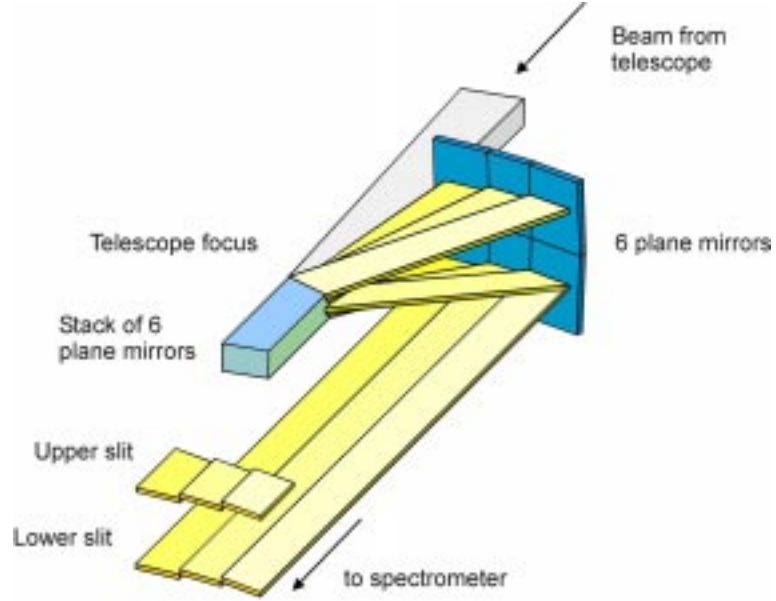


Figure 3. Close-up view of the image slicer. 12 plane mirrors rearrange the image information. Compare with Figure 2.

itself. For a 32×32 Ge:Ga detector it will be composed of two sets of 6 gold coated plane mirrors and a mechanical support structure all made of diamond turned aluminum. The first set of mirrors, located in an intermediate focus of the telescope, slices a rectangular image into 2×3 strips and deflects them into different directions while the second set of mirrors picks up light from the individual strips and aligns them into two contiguous long strips such that the pupils of the 6 single strips are coincident. The distribution of the spectra across the detector is illustrated in Figure 4.

Since the optical train is telecentric at the location of the entrance slit (see Wolf et al. 1998), the recombined 6 single strips are optically indistinguishable from two single long slits. The fact that the resulting slits look stair-like shifts the spectra on the detector by only a small amount with respect to each other. Each single mirror of the first set is about 12 mm long and 1.2 mm high. The area centers of the second set of mirrors all lie on a rotating parabola such that the focus of the parabola coincides with the telescope focus and the position of the entrance pupil of the unsliced image is retained at $-\infty$. The FOV of LISA was chosen 10×6 pixels. Such a rectangular format is more flexible since most of the targets do not show circular symmetry. A quadratic FOV covering 8×8 pixels is another possible configuration which can be realized with 2×4 slitlets if each slitlet is 8 pixels long.

The current basic parameters of the 3 channels are given in Table 1 for two different detector sizes. The spectrometer itself will be a modified Cerny-Turner type with the grating in off-axis Littrow configuration. The tilted exit slit can be accommodated for by rotating the slicer with respect to the optical axis by

Table 1. Current basic parameters of LISA

Range	40-70 μm		70-120 μm		120-220 μm	
Pixel scale [$''$]	1.8		3.2		5.6	
$\Delta\lambda[\mu\text{m}]$	2.3		4.0		6.5	
Detector	Ge:Ga		Ge:Ga		sGe:Ga	
Detector matrix [pixel ²]	32 \times 32	64 \times 64	32 \times 32	64 \times 64	16 \times 16	32 \times 32
Pitch [μm]	350		350		4.0	
Scale at entrance slit [$''/\text{mm}$]	2.8		2.8		2.8	
Field of view [pixel]	10 \times 6	21 \times 12	10 \times 6	21 \times 12	4 \times 4	10 \times 6
$''$	18 \times 11	38 \times 20	32 \times 19	38 \times 20	22 \times 22	56 \times 34
Slitlet height [mm]	0.7		1.2		2.0	
Slitlet length [mm]	7	14	12	24	8	20
$f_{\text{collimator}}$ [mm]	360		360		360	
f_{camera} [mm]	193		108		180	

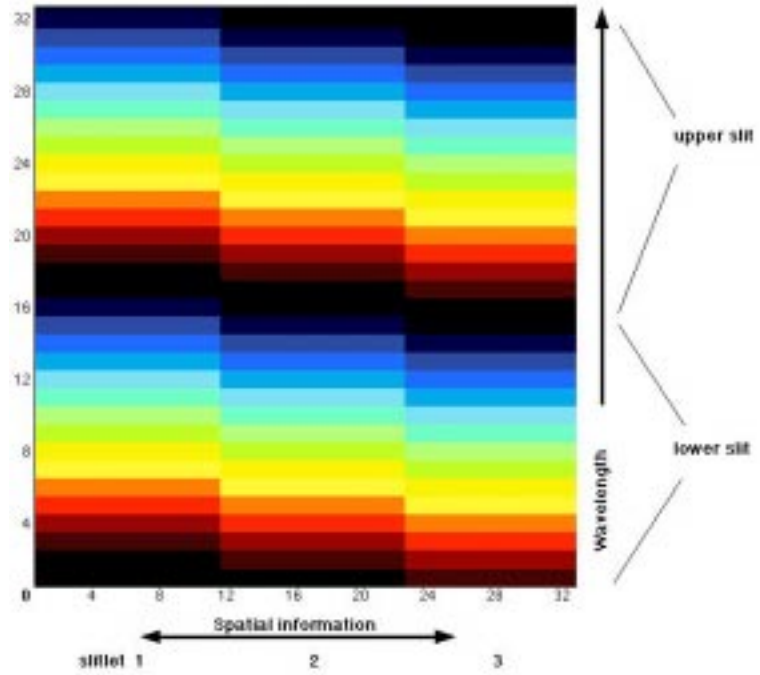


Figure 4. Distribution of the spectra across the focal plane of LISA on a 32 \times 32 pixel detector. The two entrance slits are dispersed on the same detector but do not overlap. The stair-like geometry of each entrance slit is reflected in the spectral offsets between individual slitlets.

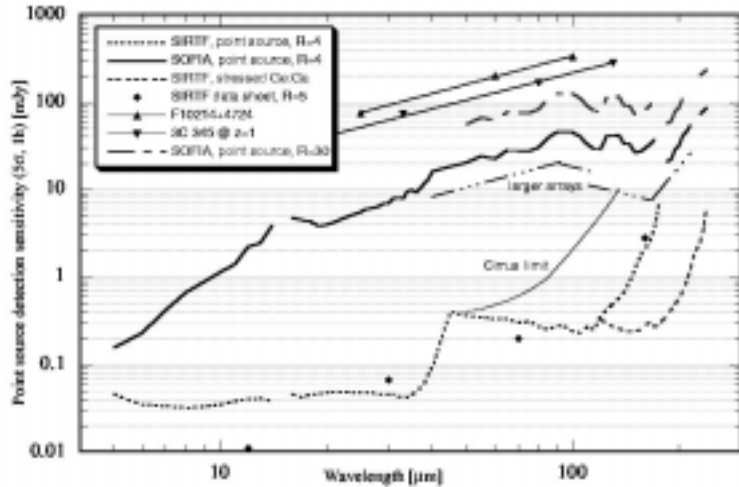


Figure 5. SOFIA's point source sensitivity for broad band imaging and low-resolution spectroscopy. Curves for the SIRTf mission are given for comparison. The triple-dot-dashed curve denotes the increase in sensitivity of SOFIA for surveys due to spatial multiplexing for 64×64 pixel Ge:Ga and a 32×32 stressed Ge:Ga array. The "Cirrus limit" curve is a rough estimate (see e.g. Franceschini et al. 1991 and Herbstmeier et al. 1998 for details). The far infrared sensitivity for a spectral resolution of 30 is denoted by the dot-dashed curve.

the off-axis angle (not shown in Figure 1). Collimator and camera mirror are off-axis parabolas. Diffraction effects at the slicer have to be taken into account since in the worst case the height of a slitlet is only about 10 wavelengths across. Behind the slit the beam will flare to $f/11$ instead of $f/30$ perpendicular to the slit. This leads to an elliptical pupil on the grating with an axis ratio of about 2.5:1. The background on the detector, however, will not be enhanced since the cold Lyot-stop further up in the beam has already limited the background flux.

4. Scientific potential

The current design of LISA is based on the experience with 3D, a near-infrared imaging spectrometer (Krabbe et al. 1996, Weitzel et al. 1996). The expected optical transmission of the slicer will be about 95%, the area covering factor of the detector will be 80% yielding an optical efficiency of 75%. If the target fits within LISA's FOV, the multiplex gain over a set of filters is about 13. Between 12 and 14 spectral positions are recorded per integration under background limited conditions. An instrument using n narrow band filters across the spectral range $40 - 220 \mu\text{m}$ will be about $n/3$ times less efficient provided that the other losses roughly balance each other. With larger arrays the multiplex advantage of an imaging spectrometer will be even higher by about the ratio of the number of pixels.

A model calculation on SOFIA's point source sensitivity using conservative assumptions is shown in Figure 5. For a spectral resolution of 16 instead of 4 the sensitivity curves are for 2.5σ instead of 5σ and 1hour integration. The broad band SEDs of IRAS10214+4724 and 3C-234 redshifted to $z=1$ are shown to illustrate SOFIA's sensitivity. All IRAS sources lie well above these curves. Between $40\mu\text{m}$ and $100\mu\text{m}$, LISA's sensitivity ranges between 40mJy and 70mJy per beam.

LISA will be able to determine the spectral energy distribution (SED) as well as broad spectral features in galactic and extragalactic targets. On extended objects, the spectral images can be decomposed into components of different temperature and spatial morphology. Applications are widespread. In star forming regions, the interaction between young stars and their environments, their outflows and dynamical evolution (e.g. T Tauri stars, HH objects, AeBe stars) can be investigated in detail. Dust disks and the evolution of protoplanetary conditions can be studied on Vega like main sequence stars (e.g. Vega, βPic). Not much is known about the expanding envelopes of more massive evolved stars during their AGB phase and evolution into protoplanetary nebulae. Interaction between ejecta from violent supernovae explosions and interstellar matter leads to progressing shockfronts, which heat up and process dust and gas of the surrounding molecular clouds. In our solar system low resolution spectroscopy will be an important tool in analyzing the composition of solids and ices on planetary surfaces and in their atmospheres as well as on asteroids and in comets.

The dust content and temperature composition of external active and luminous galaxies like Seyferts, starbursts, or interacting systems will be investigated by obtaining the (spatially resolved) SEDs of the different components and thus constraining the physical processes involved in the energy production. A special population are cool and/or very red objects (e.g. VERO's). Emphasis will be on identifying and studying the colder components in these targets. LISA will thus complement the camera with an efficient tool for analyzing the broad spectral characteristics of targets, which will be discovered and/or studied with SPICA.

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